

## Specification

Photodynamic therapy equipment, method for controlling  
photodynamic therapy equipment and method of photodynamic  
5 therapy.

This application is based on and claims priority to Japanese  
Application No. 2003-176687, filed on June 20, 2003 and  
International Application No. PCT/JP2003/016344, filed on  
10 June 19, 2003 designating the U.S., the entire contents of  
both of which are hereby incorporated by reference.

## Technical field

The present invention relates to photodynamic therapy  
15 equipment, a method for controlling thereof and a method of  
photodynamic therapy. More particularly, the present  
invention pertains to photodynamic therapy (superficial  
lesion preserving therapy) equipment, which can damage the  
deep-lying lesioned part while preserving the normal  
20 superficial region, without damaging, covered on the lesioned  
part in the treatment of the deep-lying lesioned part in the  
body, the method for controlling thereof and the method of  
photodynamic therapy.

## 25 Background art

Photochemical therapy (PDT; also designated as  
photodynamic therapy) may be applicable to various treatments  
in addition to the endoscopic phototherapy of early carcinoma.  
PDT is a therapeutic method, in which the photosensitive  
30 substance (photo-sensitizer) such as certain types of  
porphyrin derivatives is administered by a method of  
intravenous injection. The photosensitive substance adsorbs

and accumulates selectively in lesioned tissues such as cancer tissues to be treated, and then the light such as laser beam is irradiated to damage the lesioned tissues.

5 In PDT the photo-sensitizer accumulates selectively in the lesioned part and is sensitized by the light. A mechanism of action, in which the photo-sensitizer incorporated into the lesioned part is excited by the light irradiation to generate the active singlet oxygen as a result of transferring the energy of the sensitizer to the oxygen in the lesioned part, and the active oxygen necrotizes cells in the lesioned  
10 part, is proposed.

Various types of porphyrins used in photodynamic therapy have been reported (JP,09-124652,A(1997); WO 98/14453; JP,04-330013,A(1992); and JP,2961074,B). Various cancers  
15 (JP,07-53733,B(1995); JP,09-124652,A(1997)), autoimmune diseases (WO 99/07364; WO 98/19677; WO 98/14453) and arteriosclerosis (JP,3154742,B; WO00/59505) are reported as diseases for applying photodynamic therapy.

In photodynamic therapy, the porphyrin derivative  
20 developed in the initial stages exhibited a short absorption wavelength such as 600 nm. Consequently, there was a problem that even if a laser of this wavelength range was irradiated, the beam could only penetrate to a depth of several millimeters from the surface, and the deep-lying lesioned part could not  
25 be treated. Actually, since the laser practically used in PDT is a laser with short wavelength and low power for not damaging the normal tissue, the penetration depth is only several millimeters and is used for targeting treatment of superficial early stage cancer.

30 There was a further problem that drugs developed in the early stages exhibited no good excretion from the body and photosensitivity complications resulted (sunburn symptom).

Second generation drugs having absorption wavelengths toward longer wavelengths with superior excretory property were developed(JP,05-97857,A(1993); JP,06-80671,A(1994)) for reducing the problem of "photosensitivity disease" and providing the possibility of treating deep-lying lesioned parts. However, although such second generation drugs for PDT were developed, the technologies for controlling parameters for laser irradiation have not been established and matters in question such as optimum intensity of laser irradiation and irradiation time have not been elucidated.

As described above, since the second generation PDT drugs are expected to apply to deep-lying lesioned parts, PDT combined with the second generation drugs, which has possibility for treating from the superficial to the deep-lying lesion, and the long wavelength laser may be effective for treatment of cancer lesions invaded deeply due to progressing superficial cancer. In case of deep-lying lesioned parts with normal surface regions, which are relevant not only to cancer, damage of the healthy surface region might be expected.

For that reason, in case of a normal surface region with a deep-lying lesioned part, only highly invasive treatment with irradiating the laser beam directly to the lesioned part by inserting the laser irradiation part into the tissue was studied, and the development of PDT with a low invasive method for damaging deep-lying lesions has been thought to be difficult.

The present invention is intended to provide photodynamic therapy (superficial part preserving therapy) equipment, which is able to control the treatment depth from the superficial part to the deep-lying part of the lesion by changing the laser irradiation condition and is able to

damage the deep-lying lesioned part while preserving without  
damaging the normal superficial region covering the lesioned  
part, the method for controlling thereof and the method of  
photodynamic therapy.

5

#### Disclosure of the invention

The inventors of the present invention have extensively  
studied PDT drugs and irradiation conditions of the pulse  
laser such as the type of the laser medium, the peak intensity  
10 of the laser and repetition frequency. As a result, we have  
found that although the therapeutic efficiency of PDT (damaged  
rate of the lesioned tissues) was increased as the peak  
intensity was increased when the peak intensity of the  
irradiating beam was increased from low intensity to high  
15 intensity, the therapeutic efficiency was inversely reduced  
when the peak intensity became higher.

Namely, we have found that when the laser irradiation  
peak intensity was plotted on the horizontal axis and the  
therapeutic efficiency of PDT was plotted on the vertical  
20 axis, the efficiency of PDT was increased in the upward  
direction depending on increasing the peak intensity and the  
efficiency of PDT was decreased in the downward direction  
depending on increasing the peak intensity after attaining  
the highest efficiency in certain depths in the graph  
25 indicating the efficiency of PDT. This phenomenon means that  
the PDT therapy is valid when the peak intensity of the  
irradiating laser beam falls within a certain range, and the  
therapeutic effectiveness is reduced when the peak intensity  
becomes larger or smaller than that.

30 We have further studied the irradiation condition of  
the laser beam and the therapeutic efficiency of PDT based  
on such novel knowledge. As a result, we have found that when

a laser beam of high peak intensity likely reaching to the deep-lying part of the body was irradiated to the lesioned part of the living body, although the peak intensity was high at the time point of laser beam entry into the body, the peak intensity of the laser beam was gradually dropped due to absorption of the laser energy by the accumulated PDT drug in the lesioned part and hemoglobin in the body, and the peak intensity was dropped down when the irradiated laser beam arrived at the deeper position.

Further we have found that the peak intensity of the laser beam can be maintained within the range of the high therapeutic efficiency of PDT in the certain range of the depth and the PDT therapy could be achieved in that depth. Contrary to these findings, it is suggested that when the PDT therapy is intended to perform effectively at the fixed depth, an effect of PDT is made to increase upward by adjusting the peak intensity of the irradiating laser beam when the laser beam reaches that depth.

Further, we have studied the principle of PDT therapy, in which the energy of the PDT drug excited by the laser irradiation was transferred to oxygen atoms in the tissues to generate active oxygen causing to damage surrounding cells, and the PDT therapy, in which the irradiation depth of laser beam could be controlled.

As a result, we have found that since a fixed amount of time was required until oxygen atoms, which had been consumed locally at the position of the area irradiated by the laser irradiation, were diffused in and supplied from the surrounding tissues, the irradiation timing of the laser beam should be adjusted to the oxygen supply. When the repetition frequency of the irradiated laser beam was altered in order to change the irradiation timing of the laser beam, it was

found that the therapeutic efficiency depended upon not only the peak intensity of the laser but also the repetition frequency of the laser.

Further, we have examined whether the deep-lying lesion alone could be damaged without damaging the superficial normal region by controlling the therapeutic depth, for example, in case of the disease, in which the lesioned part was covered with the normal region (like the lesion of arterial sclerosis), and found that the deep-lying lesion alone could be damaged without damaging the superficial normal region by performing irradiation of the pulse laser of the high peak intensity.

We have further examined and completed the appropriate controlling system for laser irradiation and the catheter equipment which could be applied to PDT and used to treat the lesioned part locally.

Aspects of the present invention are as follows.

(1) Photodynamic therapy equipment for treating lesioned part by using a photosensitive substance, which is activated by a light having a peak intensity of a predetermined range but is almost not activated by a light having the peak intensity out of the predetermined range, comprising:

an irradiation means irradiating into the body a pulsed light of the wavelength having the potential for activating the photosensitive substance; and

a control means controlling the peak intensity of the light irradiated by the irradiation means,

wherein the control means controls the depth in the body, where the photosensitive substance is activated, in the position adjacent to the lesioned part by allowing the irradiation means to irradiate the light having the high peak intensity in order that the light arriving at the deep-lying lesioned part achieves the peak intensity of the predetermined

range, and controls not to activate the photosensitive substance in the superficial part of the body positioned closer to the light irradiation means than the lesioned part.

According to the photodynamic therapy equipment, since  
5 the light with high peak intensity is passed through the normal living body between the lesioned part and the light irradiation means, the photosensitive substance is not activated and the healthy living body can be preserved. Contrary to that, since the peak intensity of light is attenuated to the predetermined  
10 range for activating the photosensitive substance in the lesioned part, the lesioned part can be damaged by an action of the photosensitive substance.

(2) A method for controlling the photodynamic therapy equipment equipped with an irradiation means irradiating into  
15 a body a pulsed light of a wavelength having the potential for activating a photosensitive substance, which is activated by a light having a peak intensity of a predetermined range but is not activated by a light having the peak intensity out of the predetermined range, and a control means controlling  
20 the peak intensity of the light from the irradiation means, comprising controlling the depth in the body, where the photosensitive substance is activated, in the position adjacent to the lesioned part by allowing the irradiation means to irradiate the light having the high peak intensity  
25 in order that the light arriving at the deep-lying lesioned part is to achieve the peak intensity of the predetermined range, and controlling not to activate the photosensitive substance in the superficial part of the body located closer to the light irradiation means than the lesioned part.

30 (3) Photodynamic therapy equipment comprising:

an irradiation means irradiating a pulsed light of the wavelength having the potential for activating the

photosensitive substance, which is activated by the light having a peak intensity of a predetermined range but is almost not activated by the light having the peak intensity out of the predetermined range, and

5           a control means controlling the condition of the irradiation of the light irradiated from the irradiation means,

          wherein the control means controls the activation of the photosensitive substance by changing an irradiation  
10   condition of the light, and controls a rate of cell death damaged by an action of the activated photosensitive substance in a direction of the depth in the body.

(4) A method of photodynamic therapy comprising:

          a step administering to the body a photosensitive  
15   substance, which is activated by the light having a peak intensity of a predetermined range but is almost not activated by the light having the peak intensity out of the predetermined range;

          a step irradiating into the body a pulsed light of the  
20   wavelength having the potential for activating the photosensitive substance accumulated in the deep lesioned part of the body by the administration of the photosensitive substance; and

          a step activating the photosensitive substance in the  
25   lesioned part by an action of the light having the peak intensity within the predetermined range by irradiating the light of the high peak intensity when the light pulse is irradiated, subjecting to damage the lesioned part by an action of the activated photosensitive substance, simultaneously  
30   subjecting not to activate the photosensitive substance in the superficial part shallower than the lesioned part, and preserving the superficial part.



Brief explanation of the drawings

Fig. 1 is a graph showing conceptually a relationship between the peak intensity of pulsed light and PDT efficiency.

5 Fig. 2 is a graph showing conceptually a relationship between decrease of the peak intensity of light in case of irradiating the light to tissues and a region of depth with favorable efficiency of PDT.

10 Fig. 3 is a graph showing conceptually a relationship between rate of cell death and depth.

Fig. 4 is a diagram showing schematic construction of equipment for treating arteriosclerosis of the present invention.

15 Fig. 5 is a schematic diagram showing photodynamic therapy equipment equipped with balloon on the tip of inserted part to the body.

Fig. 6 is a flow chart showing flow in use of equipment of the present invention.

20 Fig. 7 is a drawing showing peak intensity and repetition frequency dependency of PDT effect.

Fig. 8 is a drawing showing relationship between drug breaching and peak intensity.

Fig. 9 is a drawing showing change of rate of cell death when irradiation energy density is changed.

25 Fig. 10 is a drawing showing measurement result of rate of cell death to depth in each pulse energy density when pulse number is maintained constant.

30 Fig. 11 is a drawing showing measurement result of rate of cell death to depth in each pulse energy density when amount of total irradiating energy is maintained constant.

Fig. 12 is a drawing showing measurement result of rate of cell death to depth when pulse energy density is changed

during irradiation.

Best mode for carrying out the invention

5 The present invention will be explained hereinbelow in detail.

The present invention provides laser irradiation equipment used for PDT and equipment which is able to control therapeutic depth, i.e. depth of damaged region, by changing the laser irradiation condition.

10 Further, the present invention provides equipment, which makes possible to treat a lesioned part by damaging only the deep-lying lesioned part (superficial lesion preserving therapy) while preserving without damaging the superficial normal region, when the lesioned part exists in the deep region  
15 of the tissue or the lesioned part is covered with normal membrane.

PDT (photodynamic therapy) herein means a therapeutic method for selectively damaging and disrupting lesioned tissues by accumulating a photosensitive substance (PDT drug)  
20 having affinity to the lesioned part specifically, and irradiating the light having a specific wavelength.

The lesioned part targeted for treatment by the laser irradiation equipment of the present invention is the lesioned part of a disease accompanied by abnormal cell growth in the  
25 tissue or atherosclerosis, and the lesioned part. Performing treatment terminates progress of the disease or prevents expansion by damaging the tissue lesion. Examples of diseases having such lesioned parts are cancer, sarcoma, benign tumors and arteriosclerosis accompanied by atheroma.

30 Position of generation of diseases is not limited, and the progressive level is also not limited. For example, in case of cancer, cancers from superficial early cancer to

invasive advanced cancer are included. Among them, the disease infiltrating the lesion to deep tissues, and the disease, in which the lesion is covered by the normal tissues, is more suitable for the present invention.

5           Normal tissues covering the lesioned part are not limited to the same tissue as the lesion, and when the light is intended to irradiate to the lesioned part by using the equipment of the present invention, any case, wherein the lesioned part and the region to be irradiated with light coexist, can be  
10   included.

          Examples of such diseases are intraepithelial cancer having normal epithelial surface, interstitial (interstitial cell: cells constituting the supporting tissue) cellular sarcoma existing within the tissue and sarcoma covered with  
15   the epithelial cells, diseases having normal parts (e.g. urethral wall) between the lesioned part (e.g. prostate) and the light irradiating part, when the light irradiation part is inserted into the urinary tract in case of prostate cancer and prostate hyperplasia, and diseases having normal part  
20   (e.g. capsule) which covers the lesioned part (e.g. atheroma) between the lesioned part (e.g. atheroma) and the light irradiating part, when the light irradiation part is inserted into the artery in the case of atherosclerosis.

          An embodiment of the equipment of the present invention  
25   is catheter-like equipment with a light irradiating part. Equipment of such an embodiment can be used by inserting the equipment into the lumen of a tubular tissue such as the urinary tract and a blood vessel, and is used preferably for treatment of prostate cancer, prostate hyperplasia, arteriosclerosis,  
30   bladder cancer, esophageal cancer, rectal cancer, larger intestinal cancer, cervix carcinoma, cancer of the uterine body, carcinoma of the biliary tract and pancreatic cancer.

Depth of the superficial part and the deep part of the present invention is not limited, and the superficial part means a depth of about 0.05 mm to 10 mm, 0.05 mm to 7 mm, 0.05 mm to 5 mm, 0.05 mm to 3 mm, or 0.05 mm to 1 mm from the light irradiated surface, and the deep part means a deeper part than that above.

As like the case of the urethral wall and the prostate, even in case of different tissues in the lesioned part, which is intended to be treated by damaging tissues, and the normal part, which is intended to be preserved without damaging, the normal part existing between the lesioned part and the light irradiation means is called the superficial part, and the thickness thereof is about 0.05 mm to 10 mm, 0.05 mm to 7 mm, 0.05 mm to 5 mm, 0.05 mm to 3 mm, or 0.05 mm to 1 mm. For example, the thickness of the urethral wall, which is to be preserved, for treating prostate cancer and prostate hyperplasia, is about 0.5 mm to 2 mm, and in case of treating atherosclerosis, the thickness of the membrane to be preserved, which covers atheroma to be disrupted, is about 0.05 mm to 0.2 mm.

In PDT, the photosensitive substance, which can be accumulated in the lesioned part, should be administered. The PDT drug combined with the equipment of the present invention is not limited to specific compounds and known PDT drugs can be used in combination with the light irradiating the absorption wavelength of the compound. PDT drugs and types of light (i.e. species of light source, wavelength of light, etc.) may be selected depending upon the depth of the lesioned part.

A PDT drug used in the PDT in practice at present is porfimer sodium (PHE) with an absorption wavelength of 630 nm, which is used in combination with 630 nm excimer laser.

However, since the invasion depth of the light irradiated by the excimer laser is about 2 to 3 mm, it is limited for treatment of superficial cancer.

Since the equipment of the present invention can be used  
5 for treatment of the lesioned part in the deep part, which is impossible by using the present PDT, laser light with a long wavelength for larger invasion depth can be used. Consequently, not only PDT drugs having absorption wavelengths at about 630 nm but also drugs having a long  
10 wavelength range can be used. Among them, second generation drugs having an absorption wavelength at 650 nm to 800 nm are preferably used. In addition, the second generation drug has good excretory nature from the body and the drug is further recommended in this point.

15 Examples of the second generation drug are: coumalin based drug, ATX-S10 (670 nm) (Iminochlorin aspartic acid derivative, Toyo Hakka Kogyo K.K., transferred the right to Hikari Chemicals Labs. in 2000, JP, 06-80671, A(1994)); NPe6 (664 nm) (mono-L-aspartyl chlorine e6, JP, 2961074, B); mTHPC  
20 (652 nm); SnET2 (660 nm) (tin etiopurpurin, Miravant Medical Technologies); AlPcS (675 nm) (chloro aluminium sulphonated phthalocyanine); BPD-MA (690 nm) (benzoporphyrin derivative monoacid ring A, QLT Inc.); and Lu-tex (732 nm) (Lutetium Texaphyrin) (traditional term, absorption peak wavelength,  
25 general name, place to obtain, and reference, in this order). These drugs can be used in combination. Not only the light wavelength and repetition wavelength but also irradiation light intensity can be controlled by accumulating multiple drugs having different absorption wavelength, and a broader  
30 range of lesioned parts from the superficial part to the deep part can be treated.

Administration of the drug can be performed by dissolving

the drug in proper buffer solution such as phosphate buffer saline, and if necessary, pharmaceutically acceptable additives are added. Examples of additives are solubilizing agents, pH adjusters such as acid and alkali base, tonicity agents such as ascorbic acid, diluting agents such as glucose, and isotonic salines such as sodium chloride.

The route of administration is not especially limited. It can be administered by intravenous injection, intramuscular injection, subcutaneous injection, and oral administration. For reducing photosensitivity disease, it may be administered directly to the lesioned part. For example, in cases where the diseases to be treated are arteriosclerosis and prostate hyperplasia, drug can be administered locally by using the drug delivery catheter, which is equipped with the vascular catheter and the urethral catheter, drug administration means such as needles and drug injection devices. In the conventional PDT, the PDT drug is mainly administered intravenously, and in that case, in order to accumulate the PDT drug mainly in the lesioned part and to emphasize the contrast of the accumulated PDT drug between the normal region and the lesioned part (generally, about six-fold PDT drug per unit volume is accumulated in the lesion as compared with the normal region), 48 to 72 hours are required for the light irradiation after intravenous administration, and patient had to become strained largely.

This is due to relying upon only the accumulation of the drug for selectivity of the range of PDT therapy in the conventional method, and to removal of PDT from the normal region for avoiding damage of the normal region. Especially, when the lesioned part is covered by the normal region, the PDT drug should be removed completely from the normal region for avoiding damage of the normal region, but this is

practically impossible, and in the conventional method, treatment, in which only the deep lesion is damaged and the superficial part is preserved, is impossible.

5 In the PDT equipment of the present invention, which can control the therapeutic depth, since the range of PDT mainly depends on the condition of laser irradiation, the PDT drug need not always be removed from the normal region and efficient treatment can be expected. Consequently, after administration of the PDT drug, completion of the contrast  
10 image observed by the accumulation of the PDT drug in the normal region and the lesioned part should not be delayed, and the light irradiation can be initiated immediately after administration of the PDT drug or within a short period of time.

15 The amount of PDT drug administered is not limited, and in case of systemic intravenous administration, etc., it is 0.01 to 100 mg/kg body weight, preferably 1 to 5 mg/kg body weight. In case of local administration, for example, a drug formulated in several  $\mu\text{g/ml}$  to several  $\text{mg/ml}$ , or a preparation,  
20 several  $\mu\text{l}$  to several  $\text{ml}$ , may be directly administered by infusion into the lesioned part. As explained later, since the degree of accumulation of the drug in the lesion can be monitored by the equipment of the present invention, the drug can be administered additionally according to the observation  
25 in monitoring.

The types of light species irradiated for treatment using the equipment of the present invention are not limited, however continuous or pulsating laser beams or light generated by an optical parametric oscillator (OPO) with variable  
30 wavelength is preferable.

The wavelength irradiated is 600 nm to 800 nm, and the light beam with the wavelength near to the absorption

wavelength of the PDT drug in use can be applied. Especially, the wavelength of the light generated from an OPO can be freely varied, and the lesion can be treated broadly from the superficial part to the deep part by changing the wavelength and peak intensity of the irradiating light.

Examples of laser beams preferably used are semiconductor laser beams, dye laser radiation and second harmonic waves of variable wavelength near-infrared laser beams. The light can be pulsed light such as pulsating laser beams or continuous light beams such as continuous laser beams. Pulsed light means a pulse width below 1 ms. The continuous light can be irradiated as pulsating chopped light intermittently by using a light chopper. When continuous light such as continuous laser beam is irradiated, if the peak intensity exceeds the constant value, the irradiating part is deformed by heating, and as a result it is not suitable for the superficial lesion preserving therapy by performing the high peak intensity irradiation. Consequently, when the superficial lesion preserving therapy is conducted, pulsed light is preferably used.

When the deep-lying lesion alone is treated while preserving the superficial part, pulsed light with high peak intensity is irradiated. The superficial normal region can be preserved without damage by irradiating the high peak intensity pulsed light. In case that the high peak intensity pulsed light is irradiated into the living body tissues, even if the PDT drug is accumulated, the deep-lying lesion can be damaged without damaging the superficial tissues.

When low peak intensity light is irradiated to the tissue, in which the PDT drug is accumulated, the superficial part of the tissue is damaged. When high peak intensity light is irradiated, the light further proceeds to the deep part, more



light energy is absorbed and scattered by the accumulated PDT drug in the tissue and hemoglobin in the tissue, and the peak intensity of the pulsed light is attenuated; then when it reaches to the certain constant depth, the PDT effect is increased to damage the tissue in that depth.

Namely, although the superficial part is not damaged by irradiation of the high peak intensity pulsed light, the deep part alone is damaged. In cases where the lesioned part is broadly distributed from the superficial part to the deep part, the condition of irradiating light may be altered. Namely, continuous light or pulsed light with low peak intensity is irradiated for treatment of the superficial lesioned part, and pulsed light with high peak intensity is irradiated for treatment of the deep-lying lesion.

The conditions of light irradiation may preferably be determined depending on the size of the lesioned part, the type of light used and the PDT drugs. The relationship between the peak intensity of light and the therapeutic depth can be estimated easily by using a model mimicking the tissue (e.g. a model prepared by using animal tissues).

A unit of the peak intensity of irradiating light is  $W/cm^2$ . Further, in case of performing PDT by irradiating light, the pulse energy density (irradiation dose,  $J/cm^2$ ) determines the feasibility of PDT, and the peak intensity or the pulse energy density can be determined properly according to the condition of the lesioned part. The pulse energy density can be obtained by multiplying the peak intensity of light with the pulse width, i.e. pulse energy density = peak intensity  $\times$  pulse width.

In the peak intensity of irradiating light, the range of the high peak intensity and that of the low peak intensity are not limited, and are determined properly depending on

the type of light, the depth of lesion to be treated, etc.

Even in the case of irradiation with setting the light irradiation part close to the lesioned part by using equipment with the catheter as described later, and irradiating from outside of the body, the ranges of the high peak intensity and the low peak intensity are different. For example, when the irradiation is performed to the lesioned part, where the PDT drug is accumulated from the superficial part to the deep part, the light with peak intensity which can damage the superficial part (such as 0.05 mm to 10 mm, 0.05 mm to 7 mm, 0.05 mm to 5 mm, 0.05 mm to 3 mm, or 0.05 mm to 1 mm from the surface), is designated as the light of low peak intensity, and the light with peak intensity which can damage deeper area than the above is designated as the light of high peak intensity.

Fig. 1 is a drawing showing conceptually a relationship between the peak intensity of light and PDT efficiency. Fig. 2 is a drawing showing conceptually a relationship between decrease of the peak intensity of light in case of irradiating the light to tissues and a region of depth with favorable efficiency of PDT. Fig. 3 is a drawing showing conceptually a relationship between rate of cell death and depth.

Referring to the conceptual drawing, the range of the peak intensity of the light of the low peak intensity for treating the superficial part and the light of the high peak intensity for treating the deep part in the tissue intended to be treated can be determined. The peak intensity of the irradiating light can be mentioned as the range of  $100 \text{ mW/cm}^2$  to  $5 \text{ MW/cm}^2$ . Total energy density which can be exemplified is 20 to  $500 \text{ J/cm}^2$ .

An example of the peak intensity of the light with high peak intensity is ranging from  $10 \text{ kW/cm}^2$  or more to below the

threshold value in which generating plasma on the surface of the body by the pulse irradiation. The peak intensity of the light with high peak intensity is ranging from 100 kW/cm<sup>2</sup> to 10 MW/cm<sup>2</sup>. More preferably, the peak intensity of the light with high peak intensity is ranging from 200 kW/cm<sup>2</sup> to 5 MW/cm<sup>2</sup>.

As shown in Fig. 1, in case that the peak intensity of the pulsed light is within the range of the optimum peak intensity, the photosensitive substance is activated and efficiency of the photodynamic therapy is high. In case that the peak intensity of the pulsed light is higher than the range of the optimum peak intensity, or lower than the range of the optimum peak intensity, the therapeutic efficiency is low and the photosensitive substance is not activated. The photodynamic therapy equipment and method of the present invention utilizes such property.

As shown in Fig. 2, the peak intensity of the pulsed light is attenuated during passage through the body. Consequently, in the superficial part, which was just irradiated to the body, even if the peak intensity is higher peak intensity than the range of the optimum peak intensity, it attenuates gradually to the range of the optimum peak intensity, further to attenuate to lower peak intensity than the range of the optimum peak intensity. By utilizing this, when the light arrives at the predetermined depth of the body, the peak intensity of the initially irradiating light can be adjusted to the peak intensity within the range of the optimum peak intensity.

In the body, to which the light with the peak intensity within the range of the optimum peak intensity hereinabove described is irradiated, a rate of cell death becomes above the cell fatality rate as a result of activation of the photosensitive substance. The rate of cell death means the

rate of cells damaged by an action of activation of the  
photosensitive substance. Further, the cell fatality rate  
means a criterion for the rate of cell death, in which function  
of the organ becomes unrecoverable by an action of the  
5 photosensitive substance. The cell fatality rate is different  
depending on type of organs.

As described above, since the light proceeds into the  
body with attenuating, the rate of cell death is changed  
depending on the depth. Mode of this change is shown as in  
10 Fig. 3.

As shown in Fig. 3, in the part, where the light with  
the peak intensity within the range of the optimum peak  
intensity, a range of the cell fatality is constituted, and  
in the anteroposterior regions thereof, the superficial  
15 preserved region and the deep preserved region are formed.

The range of cell fatality is the range where the rate  
of cell death exceeds the cell fatality rate. The superficial  
preserved region is the range, in which the photosensitive  
substance is not activated and the rate of cell death is below  
20 the cell fatality rate, since it is shallower than the range  
of cell fatality and the peak intensity of passing light is  
higher than the range of the optimum peak intensity. The deep  
preserved region is the range, in which the photosensitive  
substance is not activated and the rate of cell death is below  
25 the cell fatality rate, since it is deeper than the range  
of cell fatality and the peak intensity of passing light is  
lower than the range of the optimum peak intensity.

In the photodynamic therapy, the lesion is treated by  
matching the range of the lesion and the range of cell fatality.  
30 The healthy region shallower than the lesioned part is  
preserved as the superficial preservation range and the  
healthy region deeper than the lesioned part is preserved

as the deep preservation range.

When pulsed light is used as the light for irradiating the body, the repetition frequency of the irradiating pulsed light should be adjusted for increasing the PDT efficiency. This is due to as follows. The energy of the PDT drug excited by the irradiation of light is transferred to the surrounding oxygen atoms and the oxygen is converted to active oxygen and exerts its action on the cells, and as a result, the oxygen concentration of the light irradiated area is temporarily lowered, then the subsequent irradiation of pulsed light has to be delayed until oxygen is supplied from the surrounding tissues by diffusion.

Namely, if the repetitive frequency is too high, the oxygen supply becomes too late and the therapeutic efficiency of PDT is decreased, and if the repetitive frequency is too low, the irradiation time of the light becomes too long and the PDT is impossible to perform. Consequently, the repetition frequency, by which preferable therapeutic efficiency can be obtained, has a defined range.

The repetition frequency can preferably be changed depending upon the oxygen concentration in the area to be treated and the accumulated amount of the PDT drug, and the proper repetition frequency can be defined by using the model mimicking the tissues as described hereinabove. The range of the repetition frequency is not limited and is for example 1 Hz to 1 kHz.

As described above, since the repetition frequency affects the PDT efficiency, the PDT efficiency can be improved by maintaining the repetition frequency within the constant range.

Also, as explained hereinbelow, since by using the equipment of the present invention it is possible to monitor

the amount of PDT drug and the oxygen concentration of the area to be treated, the peak intensity and the repetition frequency of the irradiating light can preferably be adjusted depending on the amount of PTD drug and/or oxygen  
5 concentration.

The PDT drug excited by irradiation of light is decomposed by an action of active oxygen (bleaching). Consequently, in cases of treating a lesion reaching to the deep part and a lesion, in which the drug is evenly accumulated, when light  
10 with low peak intensity is irradiated for the first time, the PDT drug in the superficial part is successively decomposed with exhibiting the therapeutic effect. Subsequently, when light of high peak intensity is irradiated, the PDT drug in the superficial part has already been decomposed to lose  
15 activity, and the irradiated light reaches to the deep part without being absorbed by the PDT drug in the superficial part and treatment of the deep lesion can be achieved efficiently.

In order to treat from the superficial part to the deep  
20 part, treatment is performed by irradiating the light with low peak intensity at the beginning, subsequently the peak intensity of the light is preferably increased gradually. In this case, for example, the peak intensity may be changed stepwisely depending on the progress of the irradiation time  
25 or the peak intensity may be changed continuously.

(Equipment of the present invention)

Fig. 4 is a block diagram showing schematic construction of photodynamic therapy equipment of the present invention.  
30 Fig. 5 is a schematic diagram showing photodynamic therapy equipment equipped with balloon on the tip of inserted part to the body.

As shown in Fig. 4 the photodynamic therapy equipment of the present invention comprises catheter 10, the tip of which is inserting into the body, the main unit of treatment apparatus 20 connected to the catheter 10, and the optical fiber (quartz fiber) 30 inserted into the catheter 10, connected to the irradiation part 13 in the catheter 10 in one end, and connected to the main unit of treatment apparatus 20 in another end.

The catheter 10 can be a conventionally used catheter and the diameter is not limited. The proper catheter depending on the lesioned part to be treated can be used. For example, the vascular catheter can be used for treatment of arteriosclerosis, and the urethral catheter can be used for treatment of prostate cancer or prostate hyperplasia.

The catheter 10 comprises the tip element 11 constructed to tube-like structure and supply opening 12, which is connected to the tip element 11, for supplying physiological saline containing photosensitive substance or oxygen when these are deficient with treatment. The tip element 11 herein indicates a part distance from several dozen centimeters.

In the tip element 11, the light irradiation element (irradiation means) 13 is placed. The light irradiation element 13 is connected with the light source 21 hereinbelow explained through the optical fiber 30 (quartz fiber). The light transmitted through the optical fiber 30 is irradiated from the window element placed on the side of tip element to the lesioned part 41.

In order to irradiate the light from the optical fiber 30 to the lateral direction, the light is refracted or scattered by using a prism or scattering substance. The tip of the optical fiber 30 may be processed to surface roughening. Further, light scattering substance such as alumina and silica may

optionally be applied on the tip of the optical fiber 30, or as shown in Fig. 5, in case that the equipment of the present invention bears the balloon 15, these scattering substance may be contained in the balloon 15.

5           Since the irradiation should have little thermal effect on the penumbral tissues, the range of area within the lesioned part 41 irradiated by the light to the lateral direction is preferably  $0.5 \text{ cm}^2$  to  $3 \text{ cm}^2$ . Even if the irradiation area is restricted locally, the lesion can be completely treated by  
10   rotating the catheter 10 depending upon the size of the lesioned part, changing the irradiation direction and performing multiple times of the irradiation to the lesioned part.

          In case that the living body 40 to be treated is the blood vessel, for example, the lesioned part 41 is atheroma,  
15   and the preserved superficial part 42 is the fibrous membrane. Further in case that the living body 40 to be treated is the prostate tissue, the lesioned part 41 is benign or malignant tumor or inflammatory lesion, and the preserved superficial part 42 is the prostatic urinary tract.

20           In the tip element 11, the discharge opening 14 is placed close to the irradiation element 13. The discharge opening 14 spouts the photosensitive substance or oxygen supplied from the supply opening 12 into the living body 40.

          The main unit of treatment apparatus 20 includes the  
25   light source 21, the control element 22 connected to the light source 21, the concentration determining device 23 connected to the control element 22, and the light separating element 24 connected to the light source 21 and the concentration determining device 23.

30           The light source 21 generates the high peak intensity pulsed light such as semiconductor laser beam, dye laser radiation and second harmonic waves of variable wavelength



near-infrared laser beam.

The control element 22 adjusts the output peak intensity of the laser beam output from the light source 21 in order to make the output peak intensity of the laser beam to the  
5 predetermined range of the peak intensity proper to the treatment in the lesioned part 41.

The concentration determining device 23 is the device for detecting concentration of the photosensitive substance or oxygen in the body 40. The concentration determining device  
10 23 detects the concentration of the photosensitive substance or oxygen contained in the lesioned part 41 by measuring changes of fluorescence or phosphorescence generated from the photosensitive substance in the treatment.

The optical fiber 30 transmits the light generated from the light source 21 to the catheter 10, and simultaneously  
15 transmits generated fluorescence or phosphorescence to the reverse direction to the main unit of treatment apparatus 20. The fluorescence or the phosphorescence transmitted from the catheter 10 is separated from the laser beam by the light  
20 separating element 24, selected the predetermined wavelength by the proper filter and transmitted to the concentration determining device 23.

The concentration determining device 23 is able to monitor amount of PDT drug and oxygen concentration by  
25 analyzing the fluorescence or the phosphorescence. For example, since when the porphyrin ring of the PDT drug is excited, the fluorescence is generated, amount of PDT drug can be measured by measuring the fluorescence. Further, since the phosphorescence is quenched depending on the oxygen  
30 concentration, the oxygen concentration can be measured by measuring the phosphorescence.

In addition, use of an oxidative fluorescence indicator,

in which fluorescence intensity is increased by an action of active oxygen, or phenomenon, in which the fluorescence reaction of the ruthenium complex is quenched depending on the oxygen concentration by immobilizing ruthenium complex to the optical fiber, may be utilized. Measurement of local oxygen partial pressure can be performed according to the description, J. M. Vanderkooi et al., J. Biol. Chem. 262(12): 5476-5482, Issue of April 25, 1987; Japan Chem. Soc. Ed. Exp. Chem. (Spectroscopy II), pp. 275-294, 1998; and Lichini M. et al. Chem. Commun., 19: pp. 1943-1944, 1999.

The concentration determining device 23 transmits the detection result to the control element 22. The control element 22 is able to change the light irradiation condition such as the light peak intensity generated by the light source 21 and the repetitive frequency based on detected photosensitive substance or oxygen concentration.

The control element 22 may optionally be connected with solenoid valve of tank (figure not shown). In this case, when deficiency of the photosensitive substance or oxygen concentration is detected by the concentration determining device 23, the magnetic valve is controlled to open, and the physiological saline which contains the photosensitive substance or oxygen concentration can also be supplied from the supply opening 12.

The optical fiber 30 used is, for example, having diameter about 0.05 to 0.6 mm. The optical fiber 30 may optionally be used any type, if it can be stored in the catheter 10 and transmitted the light energy from the light source 21.

In the above description, the same optical fiber 30 is used for transmitting the light from the light source 21 to the irradiation element 13 of the catheter 1, and transmitting the fluorescence or the phosphorescence from the body 40.

However, the optical fiber transmitting the fluorescence or the phosphorescence can also be set independently and separately. In this case, the optical fiber for monitoring the fluorescence or the phosphorescence is connected directly to the concentration determining device 23.

In case of using the photodynamic therapy equipment 1 for treatment of prostate, the equipment may have the balloon 15 for the purpose of contacting the irradiation element 13 with the tissues. The balloon 15 is placed on near of the tip element 11 of the catheter 10.

When the equipment 1 is used for treatment of arteriosclerosis, the blood flow should be stopped in the lesion in the irradiation of the light beam. For that purpose, the balloon may be placed on the catheter 10.

The balloon placed in the equipment for arteriosclerosis can be the intravascular balloon used in the conventional catheter attached with balloon. The balloon 15 is expanded to stop the blood flow, and under such the condition, the light is irradiated to damage the lesion.

In this case, the balloon may optionally be equipped with the blood perfusion function, and the blood flow can be maintained by the blood flow perfusion function. Means for expanding balloon is not especially limited, and it can be achieved by supplying proper liquid or gas into the balloon. In this case, supply and drainage tube for liquid and gas may be equipped in the balloon.

Pressure of pressing the vascular wall by the expanding balloon is preferably at 0.2 to 1 kg/cm<sup>2</sup>. As explained hereinbefore, the irradiation element 13 may optionally be equipped to the balloon.

(Use of the equipment of the present invention)

Method for use of the photodynamic therapy equipment 1 of the present invention hereinabove will be explained. Fig. 6 is a flow chart showing flow in use of equipment of the present invention.

5       At first, the photosensitive substance (PDT drug) is administered to the body previously to accumulate the photosensitive substance in the lesion (Step S1).

      The preserved distance in the superficial part 41 is determined by the operator based on the information such as  
10   the depth and size of the lesion 41 obtained by previously performed ultrasound imaging, CT scan, plain roentgenography, MRI, etc., and the data is input to the control element 22 (Step S2). In this case, the shallower area than the depth of the lesion 41 is determined as the preservation distance.

15       The catheter 10 is inserted into the body and guided to the position close to the lesion 41 by the operator (Step S3). For example, in case of treating arteriosclerosis, the arterial catheter which can irradiate light is transferred close to the position where atheroma exists. Then the balloon  
20   is expanded to stop temporarily the blood flow.

      The control element 22 set up the light irradiating peak intensity and the irradiating pattern based on the input preservation distance in Step S2 (Step S4). The control element 22 stored previously data showing the correlation between  
25   the preservation distance and the light irradiating peak intensity necessary for achieve the preservation, and the light irradiating peak intensity and the irradiation pattern are set based on such data.

      The control element 22 irradiates the light from the  
30   light source 21 according to the setup light irradiating peak intensity and irradiation pattern (Step S5) to irradiate the light into the body from the tip of the catheter 10.

During irradiation of the light, concentration of the photosensitive substance contained in the lesion 41 is detected (Step S6). Measurement result is feedback to the control element 22, and data that the concentration of the photosensitive substance is below the predetermined value or not, is judged (Step S7).

In case of lowering the photosensitive substance below the predetermined value (Step S7: YES), even if the irradiation of light is continued under the condition as it is, the therapeutic efficiency may be worse, then in order to obtain stable therapeutic efficiency, the control element 22 makes lower the light irradiation peak intensity or promotes supplying the physiological saline containing the photosensitive substance (Step S8). Then the process is returned to the treatment in Step S6.

In case not to lower the concentration of the photosensitive substance below the predetermined value (Step S7: NO), data that the predetermined time course has passed or not is determined (Step S9).

In case that the treatment time course is not passed (Step S9: NO), the process is returned to the treatment of Step S7.

In case that the treatment time course has passed (Step S9: YES), the treatment procedure is terminated.

As explained, using the photodynamic therapy equipment 1, the lesion 41 alone can be treated by changing the irradiation peak intensity by the light source 3 together with considering the depth and size of the lesion 41. Namely, the light is allowed to pass with maintaining the high peak intensity for not to activate the photosensitive substance through the healthy superficial part 42, which is shallower than the lesion 41, and the light is irradiated to the lesion

41 at the level stronger than the level of attenuated light intensity in order to exhibit the peak intensity to exactly activate the photosensitive substance in the lesion 41, as a result the lesion 41 alone can be treated while preserving the superficial part. For example, in case that arteriosclerosis is treated, arteriosclerosis alone can be damaged without damaging the normal membrane covering the arteriosclerosis.

Since the concentration of the photosensitive substance is detected and the light peak intensity is reduced or the physiological saline containing the photosensitive substance is supplied depending on decrease of the concentration, the decrease of the therapeutic efficiency caused by deficiency of the photosensitive substance and the decrease in the efficiency of the treatment time period can be prevented.

In the method for use hereinabove, detection of the photosensitive substance concentration is explained, the method is not limited to that. The oxygen concentration in the lesion 41 of the body 40 can also be detected. Based on the result of detection of the oxygen concentration, the physiological saline containing oxygen is supplied and the light peak intensity can also be reduced optionally.

In the above method, the case that the catheter 10 is inserted into the body is explained, the method is not limited to that. The catheter 10 is attached on the skin without inserting the catheter into the body, the subcutaneous lesion can be treated.

The present invention can be applied to the treatment of prostate cancer or prostate hyperplasia. In that case, the urethral catheter which can irradiate the light, is inserted into the urinary tract, transfer the light irradiation element to the lesioned part, then the light is

irradiated to the lesion from inside of the urinary tract.  
The high peak intensity pulsed light is irradiated by using  
the equipment of the present invention, as a result, only  
the part of prostate cancer or prostate hyperplasia can be  
5 damaged without damaging the normal urinary tract.

(Method for controlling treatment depth by light irradiating  
condition)

The present invention further includes a method for  
10 controlling treatment depth by changing the light irradiating  
condition such as peak intensity and repetition frequency  
in PDT. Changes in the light irradiating condition can be  
performed by the light generating device. In this case,  
equipment used in PDT can be the catheter like equipment  
15 hereinbefore explained or the equipment equipped with the  
light generating device which can irradiate the light from  
the outside of the body. Treatment of diseases developed in  
any places of the body can be performed according to the method  
for controlling the depth of the present invention by adjusting  
20 the treatment depth.

In case of deep treatment depth, the light with higher  
peak intensity is irradiated, and in case of shallow treatment  
depth, the peak intensity of irradiating light can be reduced.  
In case of deep treatment depth, pulsed light is preferable,  
25 and in case of shallow treatment depth, the pulsed light and  
continuous light can also be used. Especially, in case that  
the normal region which should not be damaged is found between  
the lesion, which is intended to be treated, and the light  
irradiating element, controlling the treatment depth becomes  
30 effective.

In case of large thickness of the normal region existing  
between the lesion and the light irradiating element, the

light of the high peak intensity can optionally be irradiated, and in case of small thickness of the normal region, the light with slightly lowered peak intensity can be irradiated. Further, in case that the lesion to be treated is spread broadly from the superficial part to the deep part, the light with high peak intensity and the light with low peak intensity are irradiated in combination. The deep part can be treated by the light with high peak intensity and the superficial part can be treated by the light with low peak intensity. Further, since treatment efficiency can be differed not only by the light peak intensity but also by the repetition frequency of the light, the treatment efficiency can be improved by changing the repetition frequency.

The present invention is explained concretely by the following examples, but it is not limited by these examples.

#### Example 1

Control of treatment depth on light irradiation condition using arteriosclerotic athero model

Fig. 7 is a graphical representation showing peak intensity and repetition frequency dependency of PDT effect. Fig. 8 is a graphical representation showing relationship between drug breaching and peak intensity. Fig. 9 is a graphical representation showing changes of rate of cell death when irradiation energy is changed.

In a treatment for attempting reduction of arteriosclerotic stenosed volume and maintaining perfusion blood flow rate, a method for controlling treatment depth by changing the light irradiation condition (peak intensity and frequency) for treating inside of athero alone and prevent damage of penumbral tissue was examined.

With regard to arteriosclerotic athero model, mouse



derived macrophage like cell J774.1 was used. PDT was performed after contacting with the second generation photosensitive substance ATX-S10 (ATX-S10 Na(II) (K.K. Hikari Chemical Lab.)) with good excretion, concentration of 6  $\mu\text{g/ml}$  for 24 hours.

Irradiation of the light was performed with the light source: excimer dye laser (EDL-1, Hamamatsu Photonix Co., wavelength 670 nm, pulse width 10 ns); pulse energy density 1.2 to 9.5  $\text{mJ/cm}^2$  (corresponding to peak intensity 1.2 to 9.5  $\times 10^8$  W/ $\text{cm}^2$ ); and repetition frequency 5 to 80 Hz. PDT effect as evaluated by a rate of cell death using MTT after performing for 24 hours.

Result is shown in Fig. 7.

In a condition with high pulse energy density (high peak intensity), PDT effect almost disappeared. In a condition with low pulse energy density (low peak intensity), a rate of cell death at maximum 70% was obtained.

This might be caused by transient dissolved oxygen deficient. Presence of the optimum repetition frequency was also suggested.

In Fig. 8, changes of absorption of ATX-S10Na(II) at concentration 6  $\mu\text{g/ml}$  with changing irradiation energy density are shown. Absorption depends on total irradiation energy ( $\text{J/cm}^2$ ) and not on peak intensity. Bleaching of drug was not a decreased rate of cell death at high peak intensity.

In Fig. 9, changes of a rate of cell death with changing the irradiation energy density are shown. Measurement was performed in concentration of administered photosensitive substance at 25  $\mu\text{g/ml}$  and 50  $\mu\text{g/ml}$ . As shown in Fig. 9, it can be understood that a rate of cell death is different, if the concentration of photosensitive substance is different regardless of the same irradiation energy density. Result

indicates that rate of cell death can be adjusted by adjusting drug concentration.

Considering the organs, if the rate of cell death is too high, the organ may fall into organ failure, and the rate of cell death can be adjusted by adjusting concentration of drug in conformity to the type of organs.

This example indicates that the fibrous membrane can be preserved by irradiation of the high peak intensity. At the same time, it was indicated that treatment could be performed in the deep region (athero part) by means of decreased peak intensity caused by absorption. Further, it was indicated that rate of cell death could be adjusted by adjusting concentration of drug.

## Example 2

Control of superficial part preservation range 1

Fig. 10 is a graphical representation showing measurement result of rate of cell death to depth in each pulse energy density when pulse number is maintained constant.

In example 2, a rate of cell death on various depth with different pulse energy density under constant pulse number of irradiating light was measured.

10,000 pulses were irradiated under the condition of pulse energy density ranging from 0.3 mJ/cm<sup>2</sup> to 9.5 mJ/cm<sup>2</sup>, with constant pulse width and repetition frequency of the irradiated pulsed light. The rate of cell death on the depth was measured. Result is shown in Fig. 10.

In the low pulse energy density at the range from 0.3 mJ/cm<sup>2</sup> to 1.5 mJ/cm<sup>2</sup>, the rate of cell death was attenuated almost uniformly from the irradiated surface to the depth. Contrary to that, in the irradiation at pulse energy density 2.5 mJ/cm<sup>2</sup> or more, significantly low range of rate of cell

death was remained in the superficial part.

A part of low rate of cell death is preserved due to condition under the cell fatality rate. Namely, the superficial preservation range, where the rate of cell death is lower than the cell fatality rate, and the fatal cell range, where the rate of cell death is higher than the cell fatality rate, positioned deeper than the superficial preservation range are formed. In the deeper area than the fatal cell range, again the rate of cell death is lower than the cell fatality rate, and the deep preservation range is formed.

Referring to Fig.10, it can be understood that as the peak intensity of the irradiating light is increased stepwise, the depth, where the rate of cell death becomes highest, goes to deeper, and the fatal cell range is formed in the deeper place. This indicates that the higher the pulse energy density of the irradiating light becomes, the broader the area, where the superficial preservation range is formed, occurs.

It is indicated that the depth for forming the fatal cell range can be controlled by controlling the pulse energy density of the irradiating light, in other word, by controlling the peak intensity of the irradiating light.

### Example 3

#### Control of superficial part preservation range 2

Fig. 11 is a graphical representation showing measurement result of rate of cell death to depth when amount of total irradiating energy is maintained constant.

In example 3, the rate of cell death to depth in each different pulse energy density with maintaining the total irradiation energy of irradiating light to be constant was measured.

Referring to the above example 2, an example of the

superficial preservation treatment, when amount of the total irradiation energy is to be constant, is shown.

Irradiation was continued until the total amount of irradiation energy is reached to 40 J under the condition of pulse energy density ranging from 2 mJ/cm<sup>2</sup> to 9.5 mJ/cm<sup>2</sup>, i.e. the range to form the superficial preservation range, with constant pulse width and repetition frequency of the irradiated pulsed light. The rate of cell death on the depth was measured. Result is shown in Fig. 11.

High rate of cell death can be achieved by irradiating with low pulse energy density rather than irradiating with high pulse energy density. Although the rate of cell death becomes lower in case that irradiation is performed with high pulse energy density rather than in case of performing irradiation with low pulse energy density, the fatal cell range is formed in the deeper place, namely the superficial preservation range is formed broadly.

As explained, the superficial preservation range can be controlled to make the range broader or narrower. This can be performed by controlling the irradiating pulse energy density with maintaining the irradiation energy to be constant, alternatively, by controlling the peak intensity of the irradiating light.

#### Example 4

##### Control of fatal cell range

Fig. 12 is a graphical representation showing measurement result of rate of cell death to the depth when the pulse energy density is changed continuously or intermittently during irradiation.

In example 4, the rate of cell death to the depth was measured with maintaining the total number of irradiating

pulse to be constant and changing the pulse energy density during the irradiation.

Example with controlling the fatal cell range was performed as follows. The peak intensity of light was maintained initially to the low peak intensity of 1.5 - 5.5 mJ/cm<sup>2</sup> and irradiated 5000 pulses, then changed to the high peak intensity of 9.5 mJ/cm<sup>2</sup> and irradiated 5000 pulses. Other conditions were the same as in examples hereinbefore. The rate of cell death to the depth was measured. Results are shown in Fig. 12. In Fig. 12, results of measurement in the case that the peak intensity was not changed during the experiment are also indicated.

Referring to Fig. 12, according to the results with changing the pulse energy density from 1.5 mJ/cm<sup>2</sup> to 9.5 mJ/cm<sup>2</sup> during the experiment, the superficial lesion was treated at first by the irradiation with low pulse energy density at 1.5 mJ/cm<sup>2</sup>, subsequently the deep part was treated by the irradiation with high pulse energy density at 9.5 mJ/cm<sup>2</sup>. Namely, the fatal cell range was formed to the broad range from the superficial to the deep part.

As a result of changing the pulse energy density from 2.5 mJ/cm<sup>2</sup> to 9.5 mJ/cm<sup>2</sup>, and from 5.5 mJ/cm<sup>2</sup> to 9.5 mJ/cm<sup>2</sup>, the peaks of rate of cell death were exhibited in two places of the superficial part and the deep part. As explained, a number of pulse irradiation is kept constant and the peak intensity is changed during the experiment, and distribution of the rate of cell death can be controlled. Namely, the fatal cell range can be formed to the broad range from the superficial to the deep part.

Further, the case that irradiation was performed with the pulse energy density of 9.5 mJ/cm<sup>2</sup> from the beginning to the end (21 in Fig.) and the case that irradiation was performed

with the pulse energy density of  $2.5 \text{ mJ/cm}^2$  at the beginning, subsequently irradiated with  $9.5 \text{ mJ/cm}^2$  (23 in Fig.), are compared. The depth of the peak of the rate of cell death after changing to  $9.5 \text{ mJ/cm}^2$  and the depth of the peak irradiated with the pulse energy at  $9.5 \text{ mJ/cm}^2$  from the beginning to the end are almost same. Namely, it is indicated that the deepest part of the formed fatal cell range is almost same depth. In this regard, it can be understood that even if the peak intensity is changed to the different peak intensity from the halfway, the peak of the rate of cell death can be obtained with almost same depth when the irradiation is performed by each pulse energy density.

In the case irradiating with the pulse energy density at  $9.5 \text{ mJ/cm}^2$  from the halfway, another one fatal cell range is formed in the shallower part during the course of irradiation at  $2.5 \text{ mJ/cm}^2$ . Consequently, it can also be understood that the fatal cell range is formed in the broader range rather than irradiating with only pulse energy density at  $9.5 \text{ mJ/cm}^2$ .

As shown hereinabove, it is indicated that the fatal cell range can be formed in the broader range by combining with irradiation of different peak intensity rather than irradiating with the light of fixed peak intensity.

#### Industrial applicability

As indicated in above examples, in case that the light irradiation condition was made to change in PDT, decrease in PDT efficiency was confirmed in the high peak intensity, and further in case that the frequency of the irradiating light was within constant range, the PDT efficiency was preferable. In case that PDT is performed to the biomedical tissues by changing the light irradiation condition using the equipment of the present invention, when the light with

high peak intensity is irradiated, cells are not damaged in the superficial part where the peak intensity of light is high, and cells are damaged in the deep part, where the peak intensity of the light is decreased by absorption of energy with PDT drug, hemoglobin and water. As indicated, the therapeutic depth can be controlled by changing the irradiation condition of the irradiating light. Further, in case that the superficial part is the normal region and the deep part is the lesioned part, the superficial preservation therapy, wherein the deep lesioned part is damaged with remaining the normal superficial part, can be performed by using the equipment of the present invention.

All contents disclosed in Japanese patent application No. 2003-176687, filed on June 20, 2003, including the specification, claims and abstract, are incorporated within the present application by referring to all thereof.